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Cantilever Steel Industrial Building Located on a Rocky Hill

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Abstract

The object of the paper is an industrial building, part of a vineyard, located in a rocky zone of Arad County Romania. The investor and architect requirements led to locate the building at a height of 14.00 m, partially supported by the rocky wall of the hill at one end, while the other end is supported by a reinforced concrete rectangular tower, built near the hill. The show room area (located into a glazed cantilever zone of the building) spans 10.0 m beyond the support tower. Thus, most of the building spans in the air, creating an impression of "suspension". The paper describes some of the problems confronted by the structural engineer during the design phase, also influenced by architectural concepts.

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Keywords: rocky hill; cantilever; long span; suspension effect;bridge structure; concrete pillar;

1. Introduction

The subject of present paper is a new industrial building, part of a wine production complex, located in a rocky zone of Arad County (western Transylvania) with a particularly difficult ground configuration. This site characteristic (i.e. abrupt slope of the hill) has generated considerable difficulties to the whole design team, both architect and structural engineer, imposing as final solution a two level structure. By this solution, the lower building, with a function of wine storage (cellar), was located at the bottom of the slope while the upper one (quite unconventional and actual object of the paper) spans over it, partially supported by the rocky wall. Being involved as a structural engineer in the

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design process, the authors describe the encountered problems and subsequent solutions adopted, focusing on some sensitive aspects of the project.

2. Site description and ground condition

Fig. 1 – Abrupt 14.0 m rocky wall.

A short description of the site, from ground condition point of view, is quite relevant and fully justifies further technical solutions. Figure 1 presents the site configuration and the abrupt 14.0 m step represented by the existing rocky wall. As a result of the performed geotechnical survey (following two 8.0 m deep rock drilling), starting from the surface, successive layers of vegetal soil, then altered / cracked volcanic rock and deeper compact volcanic rock have been found. At 2.50...2.80 m depth (recommended depth of foundation), semi-compact rock with a conventional allowed pressure p-conv=500 kPa has been identified. Furthermore, a low geotechnical risk of foundation ground damage has been estimated by this study, by underground water or cracking of the rock.

At the same time, landslide danger still persisted, starting from the top of the presented wall, under upper building pressure. Besides the conclusions of the geotechnical survey issued after two drillings only, supplementary caution had to be taken with the occasion of up-hill infrastructure excavations, trying to identify ground aspect and possible rock crack initiating (in order to avoid an overall collapse of the rocky wall by global shear).

3. Architectural concept

Considering the investment character and the site characteristics previously described, the architect had to respond to a very complex task, partially imposed by the technological flowchart and partially by client requirement of aesthetic and commercial brand nature [1]. The technological flowchart is presented in figure 2, for both buildings, i.e. the lower building having mostly a function of wine storage (wine cellar) respectively the upper building with double function of industrial processing and commercial (show room for wines).

As for the aesthetic and brand requirement, the Italian investor has required a specific (or “customer tailored”) architecture for the type of commerce in which the company is involved, in other words wine market. The new erected constructions, sheltering modern technology (symbolized by the spots in fig.2), had to be “hidden” under a special finishing adapting them to the rocky environment, to the vegetation and to region traditions. Thus, the upper building (45,0 m long, 20,0 m wide and 6,30 m high) completely built of steel and having an actual cladding of sandwich panels [2], was required to have the outer layer of ivy leafs (hedera) over its whole perimeter, in complete agreement with hill vegetation all around. Such natural finishing, though adapted to the idea of “old fortress invaded by hedera” is quite unusual for an industrial/ commercial building nowadays (actually built of steel and reinforced concrete!) giving some supplementary problems to the architect in detailing process and to the structural engineer as well. Figures 3 and 4 give an image about the planned building complex and its adaptation to site geography, as given by the architects.

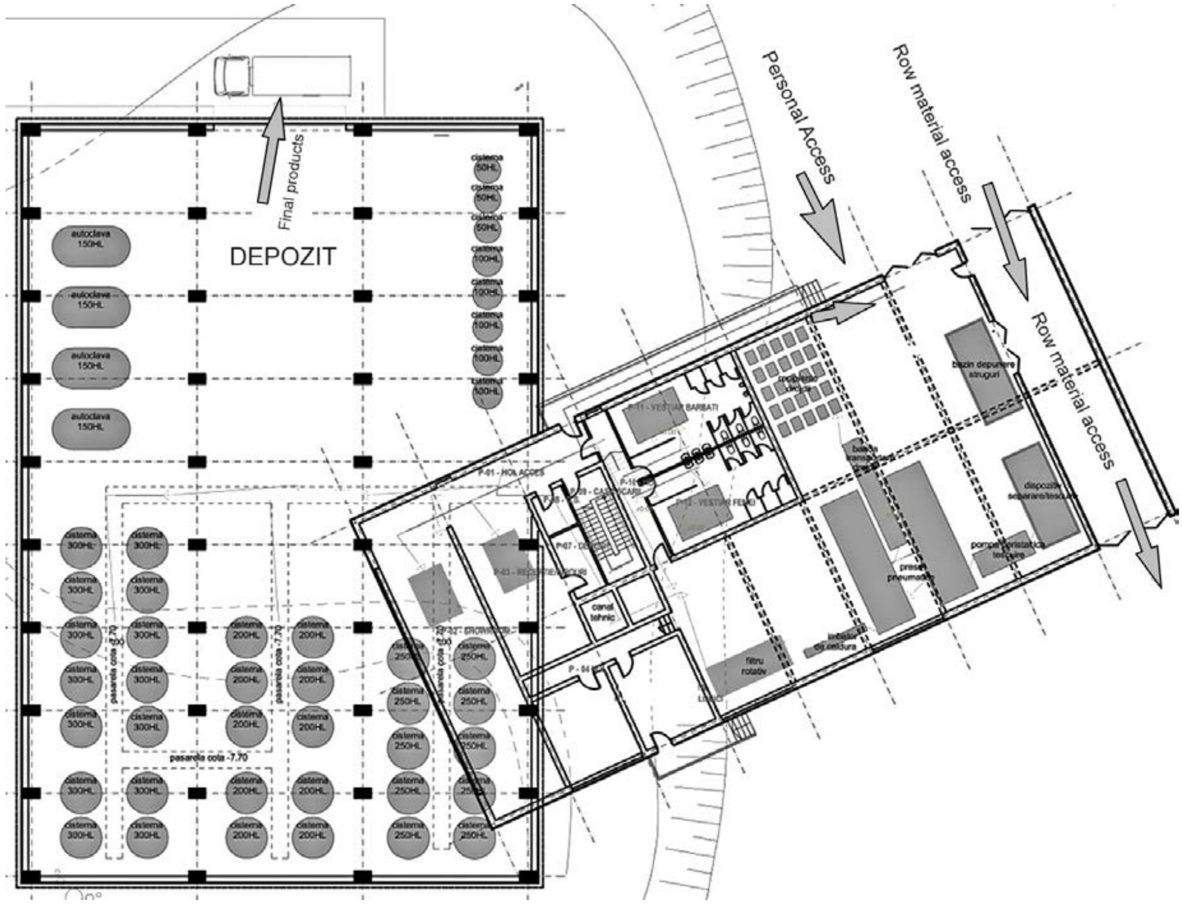

Fig. 2 – Technological flowchart of the industrial building.

Actually, the adaptation of upper building (object of the paper, presented in figures 3 and 4) to site configuration is leading to a totally unconventional architecture, where one end of the building rests on the rocky hill (on a length of 15.0 m from the total length of 45.0 m) while the rest is supported by a single massive concrete pillar in form of a reinforced concrete tower. Thus the remaining end of the building, spanning beyond this concrete tube, becomes a 10.0 m long cantilever zone [3]. From its position, this particular zone, with a large glazed gable wall (see figure 3), offers an excellent sight down-hill and over the small town of Pâncota. Therefore, the architect has placed in this zone of the building the wine show-room and a small restaurant.

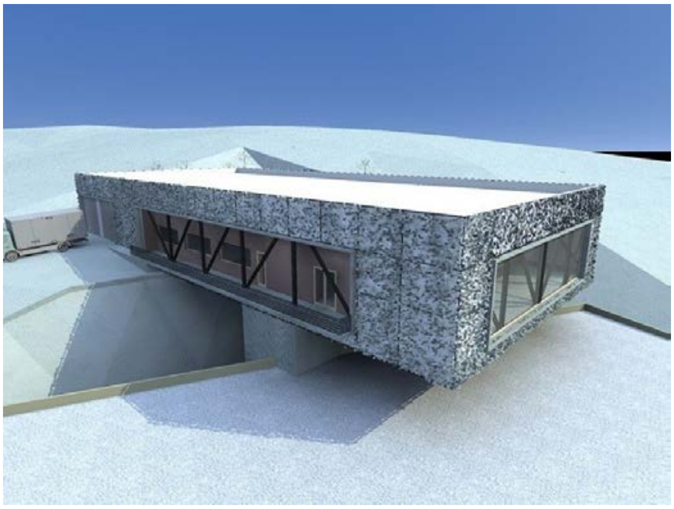

Fig. 3 – 3D virtual image of the upper building.

Fig. 4. Scale model of the complex.

As ingenious as it appears from architectural point of view, such unconventional demand (with a whole building working as a huge cantilever over a span of 10.0 m) is putting a considerable pressure on the structural engineer to find a suitable design solution.

4. Structural solution versus architectural demand

To satisfy the architectural requirements the structural engineer has employed a 3D steel structure somehow similar to a bridge structure. A layout and elevation of the structural solution applied in this case are presented in figure 5.

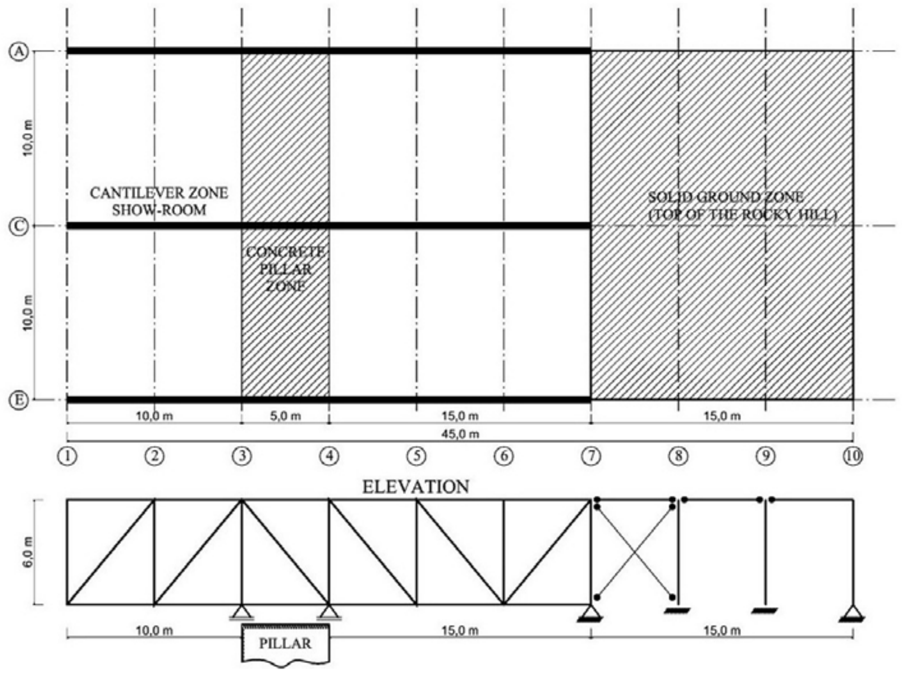

Fig. 5 – Layout and elevation of presented steel structure.

Three main lattice girders, built of hot rolled European profiles, similar to the main girders of a bridge, were provided on the longitudinal direction of the building (i.e. grid axes A, C and E) following the direction upon which the cantilever end zone is working in bending. For each lattice girder, the support points are located on the transversal grid axes 3, 4 and 7 (see figure 6). On the transversal direction of the building, on each axis, castellated steel beams with circular openings were provided, both at decking and roofing level of the building, thus completing the 3D steel structure in a way somehow similar to a bridge. The following loads are acting on the described structure: dead load of the steel framework, concrete decking package (4.5 kN/m^2), roofing package (1.4 kN/m^2), masonry partition walls; cladding system load (including ivy layer), imposed load in the show-room and restaurant (4.0 kN/m^2), imposed load in the technological zone (4.0 kN/m^2). Also climatic loads were considered, as snow load with characteristic value according to Romanian snow map (1.5 kN/m^2), wind load with characteristic value according to Romanian wind map (0.5 kN/m^2. The earthquake load spectral characteristics: peak ground acceleration ag=0.12g; spectrum corner period T_C=0.7 sec; β_0=2.75; normalized elastic spectrum function $\beta(T)$ according to the Romanian Seismic Code [4];The partial safety factors corresponding to each load type, the load combinations and subsequent combination factors were adopted to the Romanian code harmonized with Eurocode package [5]. Following the “bridge” structural model, a composite decking system was provided for all the suspended zone of the building, including the cantilever end (i.e. on a length of 30.0 m) using Φ20mm diameter Nelson stud connectors welded on the secondary castellated beams, plus 12 cm net thickness concrete reinforced slab. Concrete class C25/30 to the Romanian Code was used. Trapezoidal sheet 60 mm deep per 1.0 mm thick with side prints (specially made for composite decking) was used as a lost formwork. The composite decking, with its strong diaphragm effect, has a considerable contribution to link together the main elements and provide a 3D structural response as planned. A lightweight (terrace) roofing system was provided, built of 153 mm depth/ 1.5 mm thick trapezoidal steel sheet (no purlins provided), plus 150 mm mineral wool thermal insulation layer plus PVC membrane as hydro insulating layer plus a 5 cm thick protection layer of mono-granular gravel. Sandwich panel 100 mm thick were chosen to provide the actual thermal insulation and waterproof hall cladding [6], dressed in vegetation (ivy leafs) beyond its outer skin.

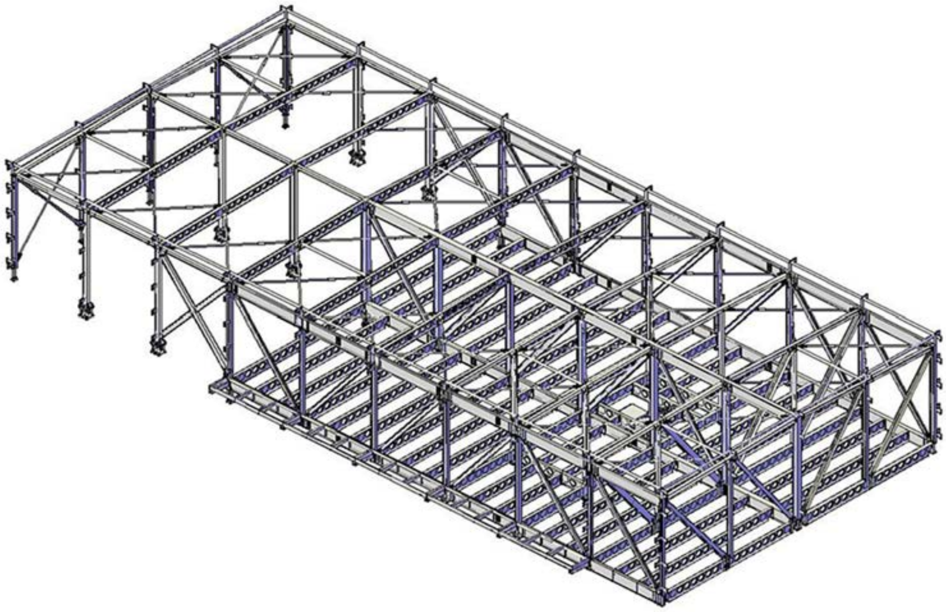

Fig. 6 – 3D TEKLA image of the presented steel structure.

External galvanized steel grid 100x100x5 mm (supported by steel plate brackets welded to the main structure) was provided all over the building perimeter to sustain the outer vegetal layer of hedera (outside panel cladding). The relation between this randomly growing vegetation (and thereby producing a randomly variable dead load) and its support structure made of steel, as well as the possible corrosive role of the vegetation on steel elements remains to be observed in the future, as this architectural solution is totally unconventional.

Figure 6 is presenting a 3D image of the designed steel structure (building main frame), as an output of TEKLA CAD programme. The three longitudinal lattice girders are visible, allowing for the deflection control of cantilever zone of the building. Actually, this is initiating an interesting discussion concerning some sensitive aspects of the structural analysis and subsequent project solutions.

5. Discussion on some sensitive structural aspects

During the structural design process, some sensitive aspects came to light and were solved by the design team. A first problem was related to deflection control at the extreme top of the cantilever zone of the building. As the designer was dealing with the whole upper building spanning 10.0 m over the lower storage hall under it, the need for deflection control was extremely severe. The employed SLS criterion limiting the vertical deflection was δ_{all} = 10.0 m/350 = 0.029 m = 29.0 mm. After several attempts and corrections (including structural modifications) performed in the analysis phase, the maximum vertical deflection at the top (in point C1) resulted δ_{act}= 29.0 mm = δ_{all}. Another sensitive aspect concerning the cantilever zone is the earthquake action on such construction parts, i.e. long cantilevers. The real seismic action has a totally random direction in the 3D space and therefore, according to the Romanian Earthquake Code [4], it is compulsory to consider, besides the horizontal components of the earthquake action, the vertical one too. Thus a maximum vertical deflection of 32.0 mm under earthquake load combination resulted in point C1 at the top, slightly exceeding the allowed limit. However, considering the stiffening role of the composite decking working together with the steel beams [7, 8], this value was allowed by the designer, as practically acceptable. An image of the decking structure during construction is presented in figure 7.

Considering the fact that the steel structure remains partially exposed to outer climate and consequently to temperature changes / variations, the effect of this type of loading had to be considered. This was done by “freeing” the structure supports over the concrete pillar to longitudinal deformation in a manner similar (also) to a bridge and thereby eliminating possible stress produced by temperature. At the same time, the fixed supports of the "bridge" girders were established in axis 7, on the top of the rocky hill. Eliminating the possible (important!) horizontal forces from temperature which could have acted at the top of the concrete pillar if temperature deformations were restrained and allowing only for the vertical forces on the building supports is contributing to a rational design of this large hollow element made of reinforced concrete. Thus, the overall bending of the pillar (in fact a tubular building 14,0 m high, including vertical technological channels, the stair case and some technological rooms) is mostly avoided, bringing economy for this structure itself as well as for its foundation.

Fig. 7 – Decking structure during construction.

Fig.8 – Long span cantilever of the building.

6. Conclusions

An industrial steel structure designed by the architect in an unconventional way to respond to client specific demand (related to wine industry or commercial brand) and also to the difficult geography of the site was presented. The special character of the architectural project has imposed a number of difficult problems to the structural engineer, often requiring special care for structural analysis solution, checking of the steel elements or detailing. The "bridge" concept was applied to the required steel structure, made of European profiles, supported by the rocky hill at one end and by a large concrete pillar at the opposite end, which is further on extended as a long cantilever over a span of 10.0 m (presented in figure 8).

At present time, the building is fully completed and functioning.

References

[1] T.Garnier, Une cite industrielle: Etude pour la construction des villes. Architectural Theory. From the Renaissance to the present. TASCHEN GmbH 2006, pp. 442-453.
[2] R. Wiesinger, Sandwich panels. Applications guide. Copyright Ingineurburo fur Metall-u. Maschinenbau. Version 10/ 2009
[3] C. Siegel, Structure and form in modern architecture. Space frames. Crosby Lockwood& Son Ltd. 26. Old Brompton Road. London SW7, 1962, pp. 181-189.
[4] ***P100-2013-Romanian Seismic Design code-Provisions for Buildings -2013
[5]***SREN 1990-2004 Romanian Code: Basis of Design to EN 1990-2002
[6]***European Recommendations for the determination of loads and actions on sandwich panels. ECCS Technical Working Group 7.9. Sandwich Panels and Related Structures. 1.st Edition, Nr. 136/2015
[7]***SREN 1994-1-1. Eurocode 4: Design of composite steel and concrete structures-Part 1-1: General rules and rules for buildings
[8] ***SREN 1993-1-1, Eurocode 3: Design of steel structures-Part 1-1: General rules and rules for buildings